CHAPTER 6

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
BACKWASHABLE DEPTH FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the NSF Equipment Verification Testing Plan for evaluation of water treatment equipment utilizing backwashable depth filtration. This Testing Plan is to be used as a guide in the development of the Field Operations Document for testing backwashable depth filters, within the structure provided by the NSF Protocol Document, "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

The procedures and methods described in this test plan and in the referenced NSF Protocol Document shall be used as guidelines for the development of the Field Operations Document. The procedures and methods shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific backwashable depth filtration equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Field Operations Document shall include Tasks 1 through 6 as described later in this document.

2.0 INTRODUCTION

Water treatment equipment employing backwashable depth filtration is used primarily for removal of *Giardia* and *Cryptosporidium* from surface waters, as well as for removal of turbidity and other particulate matter. In some cases, clarification processes may be used to pretreat water at backwashable depth filtration plants.

This Equipment Verification Testing Plan is applicable to the testing of package water treatment equipment utilizing a backwashable depth filtration process train. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used by the Field Testing Organization to determine the optimum treatment scheme and most appropriate testing schedule at the specific geographical location or locations where testing is carried out. The second phase is Verification Testing, which will evaluate performance of the equipment under a range of raw water quality conditions. Verification Testing will be done during one or more periods when the source water or feed water quality is appropriate for testing the range of water quality conditions that need to be evaluated. Development and execution of well-documented testing covering a wide range of water quality conditions has a better chance of minimizing subsequent on-site testing which states may require before approving use of the equipment at specific locations.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan will be contracted with a state-certified or third party- or EPA-accredited laboratory.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in the backwashable depth filtration Verification Testing program. Tasks A and B are sequential tasks done before Verification Testing. Tasks 1 through 6 are to be done during Verification Testing and have overlapping time frames.

4.1 Task A: Characterization of Feed Water

The objective of this Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, the operating conditions that result in effective treatment of the feed water should be evaluated, along with equipment performance, particularly with regard to rate of head loss increase and turbidity or particle breakthrough. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for a period of 30 days, or longer, during one or more testing periods to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken, including turbidity measurement and particle counting.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include filtration rate and filter headloss. Equipment performance includes rate of filter head loss gain and length of filter run.

4.6 Task 4: Microbiological Contaminant Removal

The objective of this task is to evaluate removal of microbiological contaminants or surrogates during Verification Testing by measuring removal of protozoan-sized particles naturally present in the feed water or by evaluating removal of protozoa or protozoan-sized particles seeded in the feed water, or by undertaking a combination of the above techniques.

4.7 Task 5: Data Management

The objectives of this task are to establish an effective field protocol for data management at the field operations site and for data transmission between the Testing Organization and the NSF for data obtained during the Verification Testing and to develop statistical analyses of certain test data.

4.8 Task 6: QA/QC

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during backwashable depth filtration equipment Verification Testing.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6) are designed to be carried out over one or more testing periods of 30 days or longer, not including mobilization, start-up, and Initial Operations. Each testing period should, if possible, include a minimum of three complete filter runs. At least two complete runs must be carried out, even if this requires more than 30 days. A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's claims. For example, a good challenge for a backwashable depth filter would be a testing period during which the feedwater exhibits high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment that may rapidly clog such filters. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 30 days. The purpose of the 30 day test period is to demonstrate the level of filtered water turbidity that the equipment can produce at the test site and could be helpful in showing whether changes in the pH of the feed water affect filter performance. The 30 day test period should also evaluate equipment performance under a range of circumstances including attainment of terminal head loss, backwashing, and starting new filter runs.

6.0 DEFINITIONS

Definitions that apply for backwashable depth filtration processes include:

6.1 Backwashable Depth Filter: A bag filter, cartridge filter, or granular media filter intended to filter uncoagulated water and to be backwashed when terminal head loss is attained or turbidity breakthrough occurs.

6.2 Bag Filter: A non-rigid fabric filter in which flow generally is from the inside of bag to the outside. One or more filter bags are contained within a pressure vessel. Bag filters generally do not employ any chemical coagulation, if pretreatment is employed. The pore sizes in the filter bags designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that bacteria, viruses and fine colloidal clays would pass through. Bag filters would be tested under this test plan only if a

manufacturer produced a bag filter that was intended to be cleaned by backwashing rather than replaced when terminal head loss is attained.

6.3 Cartridge Filter: A rigid or semi-rigid self-supporting filter element in which flow generally is from the outside of the cartridge to the inside. One or more filter cartridges are contained within a pressure vessel. Cartridge filters generally do not employ any chemical coagulation, if pretreatment is employed. The pore sizes in the filter cartridges designed for protozoa removal generally are small enough to remove protozoan cysts and oocysts but large enough that viruses and fine, sub-micron colloidal clays would pass through. Cartridge filters would be tested in this plan only if the cartridge is designed to be backwashed rather than replaced when terminal head loss is attained.

6.4 Filtration: A process for removing particulate matter from water by passage through porous media.

6.5 Granular Media Filter: A deep bed filter containing fine granular media that is used to filter water that has not been coagulated. These filters rely on straining particles out of water in the fine pores of the filter media or on attachment of particles to the filter media.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the backwashable depth filtration equipment to be tested. This task should be undertaken with great care, because of the possibly limited capability of backwashable depth filters to remove fine colloidal clays that cause turbidity in many surface waters and because feed waters having high concentrations of particulate matter such as algae, particles consisting of plant material, or sediment might rapidly clog such filters, necessitating frequent backwashing of clogged filters.

If the source water used as feed water for the testing program has an excessive amount of the fine turbidity-causing particles, these filters may not be able to produce filtered water turbidity which meets the requirements of the Surface Water Treatment Rule. Because backwashable depth filters are not intended to remove viruses, the entire burden of virus control falls on the disinfection process when these filters are used for water treatment. Excessive turbidity in filtered water could present problems in attaining effective disinfection and would be a likely cause for rejection of backwashable depth filters by drinking water regulators.

If the source water used as feed water consistently has a very low turbidity and very low concentration of algae and other particulate matter, drinking water regulators may be reluctant to approve backwashable depth filters for applications in which the source water turbidity or particulate matter concentration is higher. The feed water quality chosen for Verification Testing can influence both performance of the filtration equipment and the potential for acceptance of testing results by state regulatory agencies.

7.2 Objectives

The objective of this task is to obtain data from one or more years for the chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested.

Factors of particular interest include conditions that affect filter run lengths, such as turbidity in runoff events following heavy rainfall or snowmelt, or algae blooms.

7.3 Work Plan

This task can be accomplished by compiling data obtained from third party sources (i.e. USGS, USEPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Turbidity, Algae, Temperature, and pH
- Total Coliform, Total Alkalinity, Hardness, TOC, and True Color
- Total Suspended Solids

Sufficient information shall be obtained to illustrate the timing and degree of variations expected to occur in these parameters that will be measured during Verification Testing. This information will be compiled and shared with NSF so NSF and the Field Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later being deemed inappropriate, so the initial characterization will be important to the success of the testing program. Seasonal as well as potential daily variations in water quality should be considered in the evaluation of feed water data.

A description of the watershed that provides the feed water shall be provided, to aid in interpretation of feed water characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) or animal activities with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a backwashable depth filtration Verification Testing program. Table 2 of this chapter gives examples of the kinds of data and the frequency of analysis that could be helpful when making an evaluation of source water quality.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance capabilities and the Surface Water Treatment Rule. If the turbidity of the feed water is substantially greater than 1 nephelometric turbidity unit (ntu) and periodically exceeds 5 ntu, producing filtered water with an acceptable turbidity may be difficult, depending on the size of the particulate matter causing the turbidity. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment by the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task and may occur during each of the periods in which Verification Testing is to be done. Initial test runs are required before the start of the first period of Verification Testing so an NSF field audit of equipment operations and sampling and field analysis procedures can be carried out during the initial test runs.

8.2 Objectives

The objective of these test runs is to assess filter run length to permit planning for challenge tests and sampling during Verification Testing. Therefore, conducting initial test runs for each testing period is strongly recommended. Testing may also be needed to demonstrate the level of filtered water turbidity that the equipment can produce at the test site and could be helpful in showing whether changes in the pH of the feed water affect filter performance.

8.3 Work Plan

Initial tests for backwashable depth filtration are to be conducted using the filtration equipment that would be used for Verification Testing, so a preliminary assessment of treatment performance can be made, especially for filter run length. During exploratory tests, information also can be developed on the extent of turbidity removal that can be accomplished when treating the source water.

8.4 Analytical Schedule

Because these runs are being conducted to determine the suitability of the technology for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the NSF will be conducting an initial on-site audit of field operations, sampling activities, and on-site sample analysis. The on-site audit will cover activities such as those described in Task 5: Data Management, and Task 6: QA/QC. During the on-site audit the FTO should be prepared to demonstrate how appropriate data management and QA/QC procedures are being applied. The sampling and analysis schedule for Verification Testing shall be followed during the on-site audit.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance capabilities with regard to water quality. If the performance was not as good as the statement of performance capabilities, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Package plant water treatment equipment employing backwashable depth filtration shall be operated for Verification Testing purposes, with the approach to treatment based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer for one or more periods of 30 days or longer and to evaluate equipment performance under a range of circumstances including attainment of terminal head loss, backwashing, and starting new filter runs.

9.3 Work Plan

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a perspective on the overall performance of the backwashable depth filter, one or more Verification Testing periods, each lasting for a minimum of 30 days, are anticipated for evaluating the performance of a treatment system. During each testing period, the filter shall be operated and backwashed, and then it should be run through at least two cycles involving operation and backwashing. If this can be done within 30 days, Verification Testing should be conducted under conditions likely to provide a wide range of feed water quality for testing purposes. During each testing period, Tasks 1 through 6 shall be conducted simultaneously.

Testing over a range of feed water quality is recommended because of the differences in water quality that occur on a seasonal basis or at different locations. For backwashable depth filtration treatment equipment, factors that can influence treatment performance include:

- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may exhibit blooms on a seasonal basis in spring, summer or fall
- lake or reservoir turnover, if this results in iron, manganese, or bottom sediments being carried up closer to the surface where they enter the source water (feedwater) intake
- temperature
- dirunal pH changes
- natural organic matter due to runoff
- feed water disinfection

It is highly unlikely that all of the above problems would occur in a surface water during a single testing period, and this results in the recommendation for multiple testing periods or multiple sites or both to capture critical events that affect water quality.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated for a minimum of 30 days. Backwashable depth filtration package treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained. When turbidity breakthrough terminal head loss is attained,

the filter shall be backwashed, and operation shall resume. The testing shall include as many cycles of filtration and backwashing as can be accomplished in the 30 days of equipment operation, but a minimum of two cycles of backwashing a dirty filter and operating the filter after backwashing shall be accomplished in each testing period, even if this requires more than 30 days of operation.

Filter runs shall not be terminated and the filter backwashed before turbidity breakthrough or terminal head loss except because of equipment failure or power interruption because data on complete filter runs are needed to fulfill the objectives of Verification Testing. If the water treatment equipment can be stopped and restarted without being backwashed, then this aspect of equipment operation shall be evaluated during routine Verification Testing and during the challenge tests described in Task 4. During routine Verification Testing filtration shall be stopped and restarted without backwashing once per day, three days per week (only if the equipment can be operated in this manner) because intermittent, stop-start operation is commonly practiced by many small water systems.

The duration of each filter run and the number of gallons of water produced per square foot (or cubic meters of water produced per square meter) of filter area or the volume of water produced by a specific model of a backwashable depth filter shall be recorded in the operational results.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 30-day period, or longer, during Verification Testing, and to collect data on at least two cycles involving backwashing a dirty filter and operating it to terminal head loss after it was backwashed. Data shall be provided to substantiate the operation for 30 days or more.

10.0 TASK 2: TEST RUNS FOR FEEDWATER AND FINISHED WATER QUALITY

10.1 Introduction

Surface waters of high quality are the most appropriate waters for treatment by backwashable depth filtration equipment. Characterization of the feed water is very important, as feed water quality can strongly influence the performance of this equipment. Backwashable bag and cartridge depth filters function by straining, so a mat or cake builds up on the filter surface and in the pores of the filter medium. If the materials being removed are incompressible, such as hard, mineral materials, the build-up of this cake may not hinder filtration seriously. On the other hand, removal of compressible particles such as algae or fragments of biological matter can cause the filter to become blinded. This might lead to unacceptably short filter runs. Turbidity of a source water may not be an adequate indicator of its suitability for treatment by these filters. The volume of water that can be filtered could vary by a factor of ten fold or greater for water of a given turbidity, depending on the nature of the particulate matter in the raw water because turbidity can not indicate whether particles are compressible or incompressible. The recommended and required water quality data and sampling schedule for feed water and filtered water quality are given in Table 2. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Field Operations Document in the statement of capabilities.

10.2 Experimental Objectives

A list of recommended and required water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 2. The actual water quality

parameters selected for testing shall be stipulated in the Field Operations Document and shall include all those necessary to permit verification of the statement of performance capabilities. If the water being filtered tends to cause rapid increases in head loss, efforts should be made to identify the nature of the particulate matter that is causing the rapid clogging.

The characterization of feed water is intended to provide sufficient information to enable State drinking water regulators to compare the quality of the feed water used in Verification Testing with the quality of source water at a site where the use of the equipment may be proposed.

10.3 Work Plan

The manufacturer will be responsible for establishing the filtration equipment operating parameters, on the basis of the initial test runs. The backwashable depth filtration equipment shall be operated continuously until turbidity breakthrough or terminal head loss occurs, unless operation is stopped and restarted for a microsphere challenge test or for routine evaluation of the effect of stopping and restarting without backwashing. When turbidity breakthrough or terminal head loss is reached, the filter shall be backwashed and filtration operations shall be resumed. This shall continue until the end of the 30-day period, or for a longer period if needed to attain two complete cycles of operation involving backwashing a dirty filter and then running until terminal head loss is reached.

Many of the water quality parameters described in this task will be measured on-site by the Field Testing Organization. Analysis of the remaining water quality parameters will be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field will be described in the Analytical Methods section below and in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures. One analytical procedure that is not required but which can prove helpful if excessive clogging of the filters is encountered is the Microscopic Particulate Analysis (MPA) for Filtration Plant Optimization (EPA 910-R-96-001.) Use of MPA for assessing filtration performance was recently described (Hancock et al. 1996).

10.3.1 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined in the Field Operations Document.

In the case of water quality samples that will be shipped to the state-certified or third party- or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for backwashable depth filtration treatment equipment, the feed water (raw water) quality and filtered water quality shall be characterized by measurement of the following water quality parameters:

- temperature (daily)
- pH (weekly)
- total alkalinity (desired weekly but optional)
- hardness (desired weekly but optional)
- total organic carbon (desired weekly but optional)
- iron (once per test period if less than 0.3 mg/L, or weekly if above 0.3 mg/L in feed water)
- manganese (once per test period if less than 0.05 mg/L, or weekly if above 0.05 mg/L in feed water)
- algae, number and species (weekly, but three times per week if filter runs are shortened by presence of algae)
- UV_{254} absorbance (desired weekly but optional)
- total coliform bacteria (desired twice per week, with samples collected at least two days apart, but optional)
- turbidity (continuous for filtered water)
- particle counts (see Task 4)

If feed water quality changes significantly at some time between the intervals for which sampling is required, sampling after such a quality change could be beneficial to the testing program if the sample data demonstrated that a wider range of water quality could be successfully treated. Therefore in some circumstances it may be advisable to collect feed water samples more frequently than indicated above.

Turbidity of filtered water shall be measured and recorded using a continuous, flow-through turbidimeter. Turbidity of feed water (before seeding of microorganisms or microspheres) shall be measured continuously using a flow-through turbidimeter or at intervals of not more than four (4) hours if a bench model turbidimeter is used for grab samples. Continuous measurement of turbidity of feed water is preferred but not required. On a daily basis a bench model turbidimeter shall be used to check the continuous turbidimeter readings.

Particle counts of feed water and filtered water shall be measured and recorded using a particle counter equipped with flow through sensors capable of detecting particles as small as 2 μm in size.

The above water quality parameters are listed to provide state drinking water regulatory agencies with background data on the quality of the feed water being treated and data on the quality of the filtered water. The required and recommended data are to be collected to enhance the acceptability of the Verification Testing data to a wide range of drinking water regulatory agencies.

10.5 Evaluation Criteria

Evaluation of water quality in this task is related to meeting the requirements of the Surface Water Treatment Rule, plus any general water quality capabilities indicated by the Manufacturer.

- Turbidity of filtered water equals or exceeds requirements of Surface Water Treatment Rule

- Water quality and removal goals specified by the Manufacturer

Where applicable, the regulations proposed in the Enhanced Surface Water Treatment Rule (ESWTR) should also provide guidance for the treatment goals established in the Manufacturer's statement of performance capabilities and shall be considered in the evaluation criteria after this rule is promulgated.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

During each day of Verification Testing, operating conditions shall be documented. This shall include descriptions of treatment processes used and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including filtration rate expressed as gallons per minute per square foot or rate of flow through the filter expressed as gallons per minute, rate of filter head loss gain, water pressure at the inlet and outlet of the backwashable depth filter pressure vessel, length of filter run and terminal head loss, and backwashing. Operating conditions are likely to be evaluated in great detail by state reviewers and are an important aspect related to approval of equipment.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

A complete description of each process in the package treatment plant shall be given. In addition if a roughing filter or other pretreatment not employing coagulation is used, that also shall be fully described. Data on the filtration equipment shall be provided and shall include the following:

- flow capacity and actual flow rate during operation, gallons per minute
- filtration rate in gallons per minute per square foot, for filters using granular filter media
- nominal pore rating of filter bag or filter cartridge and the method used to determine this pore rating if these filters are used; or the type of filtering material, effective size, uniformity coefficient, specific gravity, and depth for each layer used, if granular media filtering material is used
- number of filter bags or filter cartridges housed within the pressure vessel; or cross sectional area of filter vessel, if granular filter media is used
- maximum operating pressure of filter vessel
- volume of filter vessel
- the backwashing method and backwashing apparatus shall be fully described, including the total volume of backwash water to be used and the duration of backwash in minutes

In addition, system reliability features including redundancy of components, shall be described. Spatial requirements for the equipment (footprint) shall be stated. Some of the above requirements might be met by providing manufacturer's engineering drawings of the equipment used in Verification Testing.

During Verification Testing, backwashable depth filter operating parameters for filtration shall be monitored and recorded on a routine basis including rate of flow, filtration rate, pressure at filter vessel inlet and outlet, and maximum head loss. Every backwashing event shall be noted and recorded, and the volume of water used for each backwash shall be measured and recorded and the reason for backwashing noted. Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on the number of gallons of water that can be produced during each filter run and on energy needed for operation of the process train being tested.

A daily log shall be kept in which events in the watershed are noted if they could influence source water quality. This includes such things as major storm systems, rainfall, snowmelt, temperature, cloud cover, upstream construction activities that disturb soil, failure or destruction of beaver dams, and intermittent operation of hydroelectric generating facilities.

11.4 Schedule

Table 4 presents the schedule for observing and recording backwashable depth filtration package plant operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance capabilities. The quantity of water that is produced and meets quality criteria for acceptance will be an important factor in this evaluation.

If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: MICROBIOLOGICAL CONTAMINANT REMOVAL

12.1 Introduction

Removal of microbiological contaminants is a primary purpose of filtration of surface waters. Consequently, the effectiveness of backwashable depth filtration treatment processes for microbial removal will be evaluated in this task. Assessment of treatment efficacy will be made on the basis of testing for removal of protozoan microorganisms or by particle counting and removal of microspheres, depending on the particle removal mechanism by which the filter is expected to work. Filter backwashing typically requires some expansion of the pore structure in the filter so trapped particles can be freed and washed out of the filter. Therefore testing for removal of protozoa or of microspheres in multiple filter cycles is an important part of the evaluation of filter efficacy for these filters.

Backwashable depth filtration based on cartridge filters or bag filters would remove particles, including microorganisms, in the size range of *Giardia* and *Cryptosporidium* from water by physically straining out the particles and trapping them within the filter. This filtering mechanism requires the pore structure in the medium to be sufficiently fine to trap particles as small as 3 μm, for control of *Cryptosporidium*. The key role of physical straining for particle removal results in microspheres being appropriate surrogates for oocysts. Backwashing bag or cartridge filters would loosen or enlarge the pore structure of the filter bags or cartridges, and this would cause the absolute pore size of the filter medium to be known with less certainty. Therefore at least some of the surrogate particles used in testing should be as small as the smallest *Cryptosporidium* oocysts, which are about 3 μm in size. Microspheres used as surrogates shall be 3 to 7 μm in diameter. Microspheres in this size range can be obtained by ordering batches of microspheres in two or more sizes. At least 50% (by number or count) of the microspheres used in challenge tests must be in the 3 to 4 μm size range.

Backwashable depth filtration based on using fine granular media could work in two ways, straining and surface attachment. If the media were sufficiently small, the pore spaces in the media would be small enough to strain out particles such as *Cryptosporidium*. It can be shown mathematically that for three equal-sized spheres which are all touching, the largest sphere that can pass through the pore space or void space between the three spheres is a sphere having a diameter that is 15.47% of the diameter of the three larger spheres. Therefore for a straining mechanism to attain complete removal of *Cryptosporidium* oocysts as small as 3 μm, spherical granular filter media would need to be 20 μm (0.020 mm) in size. For spherical granular media larger than 20 μm, some straining action could occur at sites close to where larger media granules touch, but the voids or pores between the granules would be large enough to permit passage of 3 μm particles. Mathematical analysis of the relationship of particle sizes and pore sizes of non-spherical media would be extraordinarily complex, especially for angular media such as crushed anthracite or irregularly shaped media such as diatomaceous earth, and that analysis will not be attempted in this document. This analysis is presented to demonstrate that for granular media, as the size of the media grains becomes larger with respect to the size of the particle to be removed, opportunities for particle removal by straining are reduced. For the relationship of particle size to filter material size to be known, the size distribution of the filter media must be determined, as described in Task 3.

Another mechanism by which small particles can be removed in granular media filters is surface attachment. Commonly accepted filtration theory holds that for surface attachment mechanisms to function, the repulsive forces acting between the particles being removed and the filter media must be overcome. The usual means of promoting the surface attachment mechanism is to coagulate water so the negative surface charges on particles in water can be reduced or mitigated, which then enables the surface attachment to occur more readily. Coagulation can facilitate the attachment of very small particles such as bacteria, asbestos fibers, or viruses to filter media grains that are as much as 1000 times (or more) larger than the particles being removed, when coagulant dosages are such that the mode of removal is by particle destabilization rather than sweep floc removal.

When coagulant chemicals are not used, particle removal by surface attachment can still occur, but the repulsive forces acting between the removed particle and the filter grains would be greater than if coagulation had been practiced. For non-coagulated particles to be held on filter grains, the attractive forces must be greater than the repulsive forces, but the net attractive force would be less because of the absence of coagulation. Therefore non-coagulated particles would be expected to be held less securely, and they may be more susceptible to being removed from the filter grains by shear forces caused by water velocity within the granular media filter bed.

If surface attachment is believed to have a role in particle removal in granular media backwashable depth filters, testing for removal of *Cryptosporidium* oocysts or *Giardia* cysts would need to be conducted with those organisms, because of the importance of the role of surface charge of the particles being removed. Use of microspheres as surrogates would be acceptable only if the role of surface attachment was negligible or if the surface charge (zeta potential or electrophoretic mobility) of the surrogate and the specific gravity of the surrogate were very similar to those properties for the oocysts or cysts. Until such a determination can be made, testing for granular media backwashable depth filters should be done with oocysts and cysts if surface attachment mechanisms are involved in protozoa removal.

If manufacturers provide an explanation of the particle removal mechanisms that take place in their backwashable depth filtration equipment, this may aid states in evaluating the results of Verification Studies. Providing such an explanation, however, is not a requirement of this test plan.

Removal of turbidity by backwashable depth filters is not synonymous with removal of protozoan organisms because turbidity-causing particles can be much smaller than protozoa. This can result in backwashable depth filters being able to remove protozoan-sized particles while passing particles in the size range of bacteria and viruses, or the micron-sized and sub-micron-sized particles that cause turbidity. Therefore turbidity removal is not a surrogate for protozoan removal in backwashable depth filtration. Turbidity of filtered water, however, has regulatory implications. Therefore it is important to be able to satisfy filtered water turbidity requirements set forth by the U.S. EPA or by the individual states.

Use of electronic particle counting to assess protozoan removal by backwashable cartridge filters or bag filters would be appropriate only for feed waters containing large numbers of particles in the size range of *Cryptosporidium*. The pore structure of backwashable depth filters using bags or cartridges as the filter medium would be changed during backwashing to facilitate removal of trapped particles, so particles in the size range for *Cryptosporidium* oocysts, i.e. 7 μm shall be counted. In addition, particles larger than 7 μm shall also be counted. If sufficient concentrations of 7 μm sized particles are not naturally present in the feed water, use of electronic particle counting may not be capable of demonstrating adequately high log removals without seeding of microspheres in the 7 μm size range.

12.2 Experimental Objectives

For granular media backwashable depth filters the objective of this task is to evaluate removal of particles and microbiological contaminants during Verification Testing by measuring removal of microorganisms seeded into the feed water. For backwashable cartridge or bag filters the objective of this task is to evaluate removal of particles and microbiological contaminants by assessing removal of polystyrene fluorescent microspheres and particles, with use of seeded microorganisms an optional means of evaluating those filters.

12.3 Work Plan

Task 4 shall consist of particle counting and tests involving seeded microspheres, with optional use of seeded *Cryptosporidium* oocysts for evaluation of backwashable bag filters or cartridge filters. For evaluation of microorganism removal by backwashable depth filters using granular filter media, seeded *Cryptosporidium* oocysts shall be used if the filtration equipment is intended to remove *Cryptosporidium*. The additional cost of evaluating *Giardia* cyst removal is not great when *Cryptosporidium* seeding is being done, so manufacturers are encouraged to include *Giardia* cyst seeding when *Cryptosporidium* seeding challenge studies are being done. Inclusion of *Giardia* would provide data to support statements of performance capability for *Giardia* in addition to *Cryptosporidium*, for backwashable depth filters using granular media.

12.3.1 Seeding Technique

The purpose of this task is evaluation of the backwashable depth filter for microorganism removal, so any seeding of *Cryptosporidium* (or of *Cryptosporidium* and *Giardia*) or microspheres shall be done just prior to the entry of the water into the backwashable depth filtration equipment. Seeded organisms or microspheres shall be mixed (preferably by a static in-line mixer) prior to flowing into the filtration equipment. During seeding tests, the concentrated suspension of microspheres or microorganisms shall be gently stirred to maintain the particles in suspension. The concentrated microspheres shall be suspended in a solution of distilled or deionized water with 0.01% Tween 20. Microorganisms shall be suspended in distilled or deionized water with no wetting agents or detergents because of the possibility of interference with attachment of microorganisms onto granular media in depth filters. Before each run with seeded microspheres, the holding vessel shall be washed with hot water and laboratory glassware detergent and thoroughly rinsed with tap water or filtered water. The suspension shall be kept chilled during seeding. Microspheres or microorganisms shall be added to the feed water using a variable speed chemical feed pump. The preferred method of mixing of seeded microspheres or microorganisms into the feed water is with an in-line mixer that attains a head loss of about 0.3 to 0.5 feet of water during operation. Seeding of microspheres on a continuous basis shall be done for a minimum time consisting of the time needed for displacement of three volumes, i.e. three theoretical detention times, of the filter vessel plus 60 minutes. Seeding by a slug dose method shall be done in the shortest practicable time.

12.3.2 Electronic Particle Counting

When an electronic particle counter is used for evaluation of particle removal by backwashable bag or cartridge filters, particle counts in the feed water after mixing but just before entry into the backwashable depth filter shall be measured to determine the concentration of particles before filtration, and particle counts in the filtered water shall be measured. For assessing *Cryptosporidium* oocyst removal by particle counting, particles in the size range of 3 μm to 7 μm shall be counted. If appropriately sized particles are not present in sufficient densities (concentrations) in the feed water to permit calculation of log removals consistent with the Manufacturer's statement of performance capability, then particle counting for log removal should be done during microsphere challenge events.

12.3.3 Microspheres

Evaluation of microsphere removal by backwashable bag or cartridge filters shall be conducted by measuring the density (or concentration) of microspheres seeded on a continuous basis in the feed water and then measuring the density (or concentration) of microspheres in the filtered water or by determining the number of microspheres added to the feed water in a slug dose and then measuring the total number of microspheres detected in the filtered water. Microspheres used as surrogates for *Cryptosporidium* oocysts shall be 3 to 7 μm in diameter. Microspheres in this size range can be obtained by ordering batches of microspheres in two or more sizes. At least 50% (by number or count) of the microspheres used in challenge tests must be in the 3 to 4 μm size range.

The number of microspheres used shall be sufficient to permit calculation of log removals that exceed the removal capability as set forth in the Manufacturer's statement of performance capabilities. Recovery of microspheres in filtered water provides data for use in calculating definite removal percentages, in contrast to the practice of reporting removals that exceed a specified value based on

the detection limit, which would have to be done when no microspheres are detected in filtered water. For testing involving microscopic enumeration, fluorescent microspheres and an optical microscope equipped with ultraviolet illumination shall be used.

If microspheres are seeded into the feed water on a continuous basis, determination of microsphere density by means of electronic particle counting may be feasible, depending on the statement of performance related to the log removal that can be attained by the filtration equipment and depending on the density (concentration) of microspheres that can be seeded into the feed water Density (concentration) of microspheres will be a function of the rate of flow of feedwater, the total number of microspheres available for seeding, and the length of time seeding occurs. If electronic particle counting is not feasible, enumeration of microspheres in feed water and filtered water by optical microscopy shall be required.

Two techniques for microscopic analysis of water samples containing fluorescent microspheres may be used. One is the method used by Abbaszadegan *et al*. (1997) for enumeration of *Giardia* cysts and *Cryptosporidium* oocysts, and the other is the method of Li *et al*. (1997) which they used for enumeration of microspheres.

If the techniques for microsphere sampling and enumeration are based on the research work of Li *et al*. (1997) which was carried out at the U.S. EPA's research laboratory in Cincinnati, the procedures below shall be followed. Additional details may be obtained from Li (1994).

Samples of feed water seeded with microspheres and samples of filtered water shall be filtered through 1 μm pore size, 293 mm diameter polycarbonate membranes. A stainless steel filter manifold shall be used to support the polycarbonate membrane. Volume of water filtered, and the times of initiation and completion of filtration shall be noted. The filter shall be removed from the manifold and placed in a container specified by the analytical laboratory, and refrigerated until shipped to the EPA-accredited analytical laboratory. At the analytical laboratory the microspheres removed from the filter with a laboratory squeegee and by washing with about 200 mL of 0.01% Tween 20. The liquid and particulate matter removed from the membrane shall be concentrated to a volume of between 1 and 10 mL by means of centrifugation for 10 minutes at 1200 x gravity. The volume of the concentrated suspension shall be recorded. Microspheres shall be enumerated using a hemacytometer under a UV microscope at 400 magnification. A minimum of three hemacytometer counts shall be performed for each sample. The volume of suspension examined in the hemacytometer shall be recorded and used to determine the fraction of the original water sample which was ultimately examined under the microscope.

Standard Methods states that hemacytometer chambers come with detailed manufacturer's instructions concerning calculations and proper usage. *Standard Methods* contains the precaution that disadvantage of hemacytometers is that the sample must have a very high density of objects being counted in order to yield statistically reliable data. Some exploratory tests may be needed to identify appropriate volumes of treated water to filter through the polycarbonate membrane or appropriate densities (concentrations) of microspheres in the seeded feed water, so that reliable statistics can be attained in filtered water analysis. The total number of microspheres counted in the hemacytometer should be between 30 and 300 to obtain good statistical results without counting overwhelming numbers of microspheres.

If the entire flow stream produced by the backwashable depth filtration equipment can not be filtered through the 293 mm membrane filter for sampling, a measured portion of the total filtered water flow can be sampled as it is produced, or the entire flow of filtered water from a seeding test can be stored in a biologically inert clean vessel and later filtered through the 293 mm membrane filter at a rate of flow suitable for the membrane filter.

If an instantaneous slug dose of microspheres is applied and the entire volume of filtered water is saved in a biologically inert storage vessel for subsequent membrane filtration as the sampling procedure, a volume of filtered water of at least 20 times the volume of the of the water in the filter's pressure vessel shall be filtered through the backwashable depth filter and saved for sampling and analysis. The volume of the water in a filter vessel may be calculated by subtracting the volume of the filters and appurtenances in the vessel from the volume of the empty vessel or by carefully measuring the volume of water required to fill the pressure vessel of a filter with the appropriate number of bags or cartridges installed and ready for use.

12.3.3.1 Organisms Employed for Challenge Tests. Microbiological testing of backwashable depth filters employing granular filter media shall be performed by seeding *Cryptosporidium* oocysts into the feed water and by analyzing for oocysts in the feed water and in the filtered water if the Manufacturer's statement of performance capability indicates that *Cryptosporidium* can be removed by the filtration equipment. Test results (Clancy *et al*., 1993) indicate that *Giardia* removal by backwashable granular media depth filters may be greater than *Cryptosporidium* removal. The extra cost for seeding and analyzing for *Giardia* cysts is nominal when *Cryptosporidium* oocysts are being seeded, so some manufacturers may decide to include *Giardia* testing for backwashable depth filters employing granular filter media and provide testing data to support statements of performance related to removal of both *Cryptosporidium* and *Giardia*. If *Giardia* cysts are included along with *Cryptosporidium* in challenge studies, either *Giardia lamblia* or *Giardia muris* may be used, and the procedures described for the *Cryptosporidium* challenge shall be used for handling, seeding, and analyzing for both protozoa.

Cysts and oocysts shall be prepared and stored using techniques that minimize changes to the organisms to the extent practical. In particular, when cyst or oocyst removal is accomplished by surface attachment, changes in the zeta potential of the organisms should be avoided. Storage of oocysts should be in water, either with or without antibiotics added. Oocysts shall not be stored in a dichromate solution for preservation when they are to be used in challenge tests involving oocyst removal by surface attachment mechanisms. Oocysts should be less than 8 weeks old (less than 8 weeks from the date of shedding) when they are used. *Giardia* cysts should be less than 4 weeks old when used.

When testing is done with seeded oocysts, the oocysts shall be used in densities sufficient to permit calculation of at least 3-log removal, and seeding of microorganisms shall begin at start-up of the treatment equipment. The organism feed suspension will be prepared by diluting the organisms to be seeded into dilution water that is distilled or deionized and disinfectant free. The feed reservoir for the organism suspension shall be made of biologically inert material (i.e., not toxic to the organisms in the suspension.) The reservoir will be mixed continuously throughout the seeding experiment and kept packed in ice in a cooler. The seed suspension will be fed into the feedwater using an adjustable rate chemical feed pump. Mixing of this suspension with the feedwater will be accomplished using an in-line static mixer.

The analytical methods used for *Cryptosporidium* oocysts lack precision. The method required to be used for the Information Collection Rule (ICR) should be followed at the present time. When improvements to the *Cryptosporidium* method are tested, peer reviewed, evaluated by several laboratories, and then accepted by the U.S. EPA or are published by *Standard Methods*, the improved methods should be followed. EPA Method 1622 has been proposed and may be used as an alternative to the ICR method.

12.4 Analytical Schedule

12.4.1 Particle Counting

Analysis of feed water samples by electronic particle counters may be done on a batch or a continuous basis. If batch measurements are made, they shall be made for at least 8 hours each working day during Verification Testing, with samples collected and analyzed at least once each hour and in conjunction with microbiological challenges, microsphere challenges, and stop-start operations. Filtered water analysis shall be done using flow-through particle counters, equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

On days when microsphere challenge tests or microbiological challenge tests are undertaken, particle counting activities shall be coordinated with the challenge test sampling activities so particle count data are available for every sample that is analyzed for microspheres or microorganisms. On days when challenge tests are not carried out, at least eight feed water samples shall be obtained for particle counting and for purposes of comparison with filtered water so calculation of log removal of particles can be done.

Special sampling and analysis shall be done to evaluate the effect of stop-start operations that are common in small systems. If the backwashable depth filtration equipment can be stopped and restarted without backwashing, particle count data shall be obtained for three feed water samples and for three filtered water samples during the last 30 minutes before the occurrence of the daily shutdown described in Task 1, Section 9.4, Schedule. After the filter has been restarted, filtered water particle count data shall be obtained for six samples collected at five-minute intervals during the first 30 minutes of operation after restart, and then three samples of feed water shall be analyzed for particle counts as soon as practical. If the equipment can not be stopped and restarted without backwashing, filtered water particle count data shall be obtained for six samples collected at five-minute intervals during the first 30 minutes of operation after backwashing and restart, for evaluation of the effects of backwashing and restarting the filter. If feed water particle counting is done on a continuous basis, comparable feed water data shall also be obtained.

12.4.2 Microsphere Samples and Microbiological Samples

During each Verification Testing period, the filter shall be operated and backwashed, and then it shall be run through at least two complete cycles involving operation to turbidity breakthrough or terminal head loss and backwashing, even if this evaluation requires more than 30 days. During the test period, two complete filter cycles or runs shall be subjected to challenge tests with microspheres for backwashable bag or cartridge filters or with protozoa for backwashable granular media filters.

If microbiological seeding is carried out, seeding and collection of microbiological samples shall be collected from feed water and filtered water on the same schedule stipulated for microsphere samples.

During each microsphere or microorganism challenge test run, microspheres or microorganisms shall be seeded three or four times during a run. Three of these times are at the start-up of the equipment after the filter was backwashed; near the middle of the run when head loss has approached one half of the recommended terminal head loss; and near the end of the run after head loss has reached 85 to 95 percent of recommended terminal head loss. In addition, if the filter can be stopped and restarted without backwashing, after the seeding challenge and sampling in the middle of the run has been completed, the filter flow shall be stopped and preparations shall be made for another round of sampling. The filter shall be restarted and sampling shall be done again, to evaluate the effect of stopping and starting a filter that has removed a very large number of microspheres or microorganisms. This stop-start test is required for evaluation of the potential effect of intermittent operation on water quality. Inclusion of a stop-start evaluation is not required if the equipment is designed and programmed to automatically backwash every time it is stopped and restarted. If stop-start operation with the equipment is appropriate and if filter runs are expected to be longer than about four days, the stop-start operations shall be conducted as described in Task 1, but only one microsphere or microorganism challenge shall be conducted after filter restart, and this shall be done at about half of the recommended terminal head loss. The timing for challenge sampling events is presented in Table 5.

The timing for collection of samples may be different based on whether continuous seeding or slug dose seeding is used.

When microspheres or microorganisms are seeded on a continuous basis, the seeding shall be done for a duration of 1.0 hour, plus an amount of time equal to 3 theoretical detention times through the filter vessel at the rate of flow being tested. Samples shall be collected from the plant influent (feed water after seeding) and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of 3 theoretical detention times as measured through the filter vessel. For sampling purposes, the time of operation when 3 filtration vessel detention times have elapsed shall be considered time zero. Three feed water samples shall be collected, beginning at time zero, and at 0.5 and 1.0 hours. Three filtered water microsphere or microorganism samples shall be collected, beginning at time zero and at 1.0 and 2.0 hours if grab samples are collected, or if the sampling times are not long enough to result in sampling filtered water during the entire 2 hours of filtered water sampling. The filtered water sampling shall continue for one hour after seeding ceases, to evaluate the capability of the filter to retain large numbers of microspheres or microorganisms even after they are no longer present in the feed water. The exact time of sampling will be recorded so turbidity measurements can be determined at the time of sampling. During the sampling events, the time during which filtered water was sampled shall be noted and turbidity data shall be obtained which are representative of filtered water quality during sampling. If the sampling filter which is used to collect a filtered (treated) water sample has sufficient filtration capacity so that sampling can be conducted with a single sampling filter from time zero to the 2.0 hour sampling time, then a single filtered water sample may be obtained that represents a composite of the filtered water produced during the 2-hour time interval, and collecting three distinct filtered water samples is not required.

For challenge tests carried out with microspheres, volumes of feed water and filtered water to be filtered should be large enough that 30 to 300 microspheres are detected in each seeded feed water

sample. Ideally for statistical purposes 30 to 300 microspheres should be detected in each filtered water sample also. If the filtration process is highly efficient for removal of the microspheres, detection of such large numbers in samples of filtered water would not be possible. In such a case, detection of at least 5 microspheres is desirable. If removal is extremely high, detecting 5 or more microspheres in filtered water may not be possible but probably would be indicative of very high log removals of microspheres.

When continuous seeding is practiced, the seeding shall be done for the challenge testing carried out before the filter operation is stopped, but seeding shall NOT be done after the filter is restarted, in the challenge involving stop-start operation in the middle of the run. Likewise, when seeding is by slug doses, seeding shall be practiced during filter operation in the middle of the run, but after the filter is restarted, seeding shall NOT be done. The purpose of restarting the filter and sampling is to assess the possibility for previously-trapped microspheres to pass through the filter during the stress caused by the resumption of flow, and this can not be clearly established if seeding is done after the filter is restarted.

When microspheres are seeded on an instantaneous slug dose basis, dosing shall be done as rapidly as practical, in time intervals as short as several seconds. Slug doses shall be seeded at the beginning of operation, just after flow is turned on in a filter, about mid-way through the filter run, and after the filter has operated long enough to attain 85 to 95 percent of the total available head loss.

For seeding on an instantaneous slug dose basis, the number of microspheres in the concentrated suspension shall be based on an analysis of the concentrated suspension before it was dosed. When the entire production of filtered water is to be collected for sampling, this shall be done from the instant of dosing until a volume of filtered water equal to 20 volumes of the water held in the filter vessel have been collected. The volume of water held in the filter vessel may be calculated as described in section 12.3.3. For a granular media depth filter, the volume of filter media is the volume occupied by solid material only and excludes the volume of void or pore spaces. For example, if the filter vessel volume is 40 liters, and the volume occupied by filter media and support media excluding pore spaces is 10 liters, the net empty volume is 30 liters and a 600 liter sample of filtered water shall be collected and then filtered through a membrane filter as described above in the procedure of Li *et al.*

As an alternative to collecting the entire production of filtered water, a side stream of filtered water may be collected for analysis. The entire volume of the side stream shall be filtered through a membrane filter, as described above. This reduces the volume of water that must be filtered through the membrane. In calculation of log removals, the FTO must adjust the number of microspheres seeded into the feed water in proportion to the volume of the side stream as compared to the full flow of the treatment equipment. For instance if the volume of the side stream was only 10 percent of the volume of the full flow treated, the number of microspheres used for calculation of log removals would equal only 10 percent of the total number of microspheres seeded.

Microsphere samples shall be analyzed by an EPA-accredited analytical laboratory.

The Testing Organization shall then submit collected water samples to an EPA-accredited analytical laboratory for microbial testing.

12.5 Evaluation Criteria

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing.

Performance of bag filtration and cartridge filtration package plants shall be evaluated in the context of the Manufacturer's statement of performance capabilities and the filtered water turbidity requirements of the SWTR. Turbidity results will be analyzed to determine the percentage of turbidity data in the range of 0.50 NTU or lower, the percentage between 0.51 NTU and 1.0 NTU, the percentage between 1.1 and 5 NTU, and the percentage that exceeded 5 NTU. The time intervals used for determining filtered water turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be 1/4, 1/2, or 1 hour. In addition, the highest filtered water turbidity observed each day shall be tabulated. The feed water (if feed water turbidity is continuously monitored) and filtered water turbidity data collected during the 30 minute periods immediately before and following either shutdown and restart without backwashing or shutdown and restart with backwashing shall be presented in tables or graphs.

Electronic particle count data shall be evaluated by calculating the change in total particle count from feed water to filtered water, expressing the change as log reduction. The aggregate of particle counting data obtained during each verification testing period shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. Data for 3 to 7 μm particles shall be analyzed. In addition, data for the 3 to 7 μm particles plus all particles larger than 7 μm shall be analyzed. Because of possible complications in conducting electronic particle counts on feed water, 1 to 4 hour time intervals shall be used for analysis of particle counting data for log reduction of particles. In addition, particle count data for filtered water shall be presented as time series data showing trends of particle counts with passage of time. Data shall be presented showing particle counts in filtered water at time intervals no longer than one hour for the 30 days of Verification Testing. The filtered water particle count data and any available feed water particle count data collected during the 30 minute periods immediately before and following either shutdown and restart without backwashing or shutdown and restart with backwashing shall be presented in tables or graphs.

Data on the density (concentration) of microspheres or protozoa in feed water and filtered water shall be analyzed to determine the median log removal and 95th percentile log removal during that verification testing period. This analysis shall be done separately for each filter operating condition: at start-up after backwashing a dirty filter, mid-way through a run before stopping filter operation and again after restarting the filter (if restart is carried out), and after 85 to 95 percent of terminal head loss has been attained.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software or manual recording methods, or both, for recording operational parameters for the bag filtration or cartridge filtration equipment on a daily basis.

13.2 Experimental Objectives

One objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

13.3 Work Plan

13.3.1 Data Management

The following protocol has been developed for data handling and data verification by the Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available, field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook will provide carbon copies of each page. The original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Field Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the backwashable depth filtration equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each filtration test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited analytical laboratories, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be

received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.3.2 Statistical Analysis

Water quality data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants."

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Each of the conditions described in Task 4 (start of run, middle of run before flow stops, middle of run after flow is stopped and restarted, and near end of run approaching terminal head loss) shall be analyzed separately for 95% confidence intervals. Information on the differences in water quality for the beginning and the end of filter runs would be useful in evaluating the effect of starting operation after backwash and the effect of approaching terminal head loss. Data on microsphere removal in the middle of the run, before and after the filter flow was stopped, can be used to assess the effects of stopping and starting the flow in backwashable depth filtration equipment. Data collected at different times during filter runs, with different head losses, could also be used to evaluate the effect of head loss on filter performance.

14.0 TASK 6: QA/QC

14.1 Introduction

Quality assurance and quality control of the operation of the backwashable depth filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instruments within the ranges specified by the manufacturers or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters, etc. will be checked to confirm that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.4 Daily QA/QC Verifications:

- In-line turbidimeters flowrates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counters flowrates (verified volumetrically over a specific time period).

14.5 Bi-weekly QA/QC Verifications:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.6 QA/QC Verifications at Start of Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle counters (perform microsphere calibration verification)

14.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.7.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+. A 2 point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1 ^oC, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^oC to +51^oC, subdivided in 0.1^o increments, would be appropriate for this work.)

14.7.3 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement

of turbidity in the filtrate waters, and either an in-line or bench-top may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring equipment.

14.7.3.1 Bench-Top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.7.3.2 In-Line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.7.4 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle

counting during verification testing. However, other types of counters such as coulter counters or Elzone counters may be considered for use if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbiological contaminant removal.

14.7.4.1 Bench-Top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated mono-sized polymer microspheres. This calibration should be verified at the beginning of each Verification Testing period. Additionally, calibrated mono-sized polymer microspheres in sizes of 2, 10, and 15 μm should be used for the verification. The procedure is as follows:

- Analyze the particle concentration in the dilution water;
- Add an aliquot of the microsphere suspension to the dilution water to provide a final particle concentration of approximately 50,000 particles per 25 mL (2,000 particles per mL), and then gently swirl the suspension;
- Promptly analyze a suspension of each particle size separately to determine that the peak of particle concentration coincides with the diameter of particles added to the dilution water;
- Prepare a cocktail containing all three microsphere solutions to obtain a final particle concentration of approximately 1,000 particles per mL of each particle size; and
- Promptly analyze this cocktail to determine that the particle counter output contains peaks for all of the particle sizes.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement, or 3) an increase in particle counts from measurement to measurement. During the pilot study, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by hand washing using hot water and laboratory glassware detergent solution followed by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water, diluted unfiltered water, prefiltered water (if prefiltration is used), filtered water, and PFW. When several samples are collected from various pilot plant sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water.

When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;
- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);
- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;
- The volumetric flask will be slowly filled to the full-volume etch with dilution water;
- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\ Particle\ Concentration = \frac{\{MP - (1-X) \times PF\}}{X}$$

where MP is the measured particle concentration (particles per mL) in the diluted sample, PF is the measured particle concentration (particles per mL) in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

14.7.4.2 In-Line Particle Counters. Any in-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than a ten percent. Methods for demonstration of coincidence error shall be provided by the particle counter instrument Manufacturer. The rate of flow through the sensor must be within the operating range specified by the manufacturer and must be measured and documented.

The sensors of the in-line units must be provided with an updated manufacturer calibration. The calibration will be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples will be conducted. The data acquired from the counters will be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

14.8 Chemical and Biological Samples Shipped Off-Site for Analyses

14.8.1 Organic Parameter: Total Organic Carbon and UV_{254} Absorbance (UV is an Optional Parameter)

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*. TOC is a required sampling parameter. UV_{254} absorbance is an optional sampling parameter.

14.8.2 Microbial Parameters: Total Coliform (Optional) and Algae

Samples for analysis of total coliform (TC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited analytical laboratory within the time specified for the relevant analytical method. The laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. TC is an optional sampling parameter.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

14.8.3 Inorganic Samples

Inorganic chemical samples, including, alkalinity, hardness, iron, and manganese, shall be collected, preserved and held in accordance with *Standard Methods* 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.8.4 Microspheres

The membrane filters used for obtaining microsphere samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment and in the analytical laboratory, until they are analyzed. This is done to minimize microbiological growth on the membranes.

Recovery of microspheres from suspensions held in glassware shall be evaluated by preparing a suspension of microspheres in which the number of microspheres used to make the suspension is estimated, based on either the weight of dry microspheres or the volume of microspheres in liquid suspension as provided by the supplier. After the suspension is prepared and mixed until it is homogeneous, five aliquots shall be taken and counted in the hemacytometer. After the microsphere density (concentration) has been calculated, aliquots of the suspension shall be diluted and filtered through polycarbonate membrane filters having 1 μm pore size. The elution and concentration steps

described in Task 4 shall be followed, and the microspheres shall be counted in a hemacytometer. This shall be done five times, so that statistics can be developed on the recovery of microspheres in the sampling procedure.

As a check on possible interference from fluorescing organisms in the feed water, during each Verification Testing run in which fluorescent microspheres are used, a sample of feed water with no seeded microspheres shall be filtered through a polycarbonate membrane, and the particulate matter on the membrane shall be concentrated using the procedures for microsphere analysis, and the concentrate shall be examined in a hemacytometer by microscope, with UV illumination. If no objects of the size and shape of the microspheres are seen to fluoresce, displaying the same color as the microspheres, then fluorescent objects of the proper color seen in samples with seeded microspheres can be considered to be microspheres.

Microspheres may adhere to surfaces of tanks, vessels, and glassware. All glassware, holding tanks, and membrane filter manifolds must be cleaned between seeding events or sampling events.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for backwashable depth filter package plants.

15.1 Maintenance

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- motors
- valves
- mechanisms involved in washing the filter
- equipment used for cleaning filter media
- pressure filter vessel opening mechanisms, if provided
- instruments, such as turbidimeters
- water meters, if provided

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as tanks and basins.

If prefiltration equipment is used, the manufacturer should provide the same sort of information for that equipment as the information described above.

15.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the package plant equipment, both for filtration equipment and for prefiltration equipment, if that also is used. Among the operating aspects that should be discussed are:

Equipment Compatibility:

- compatibility with chemical disinfectants
- compatibility with oxidants

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter backwashing:

- criteria for determining end of filter run
- start of backwash
- appropriate backwash rates
- use of auxiliary water scour (surface wash) or air scour, if provided
- can rate of flow of backwash water be measured and controlled?
- duration of filter washing
- procedure for determining when to end backwash
- return of filter to service
- does equipment provide for filter-to-waste operation at start of filter run after the filter has been backwashed?
- can the operator stop and re-start the filter without backwashing it, or does the equipment automatically backwash the filter if flow is stopped and the filter is re-started?

Monitoring and observing operation:

- filter vessel inlet pressure
- filter vessel outlet pressure
- filter head loss
- raw water turbidity or pretreated water turbidity
- filtered water turbidity
- rate of flow
- what to do if turbidity breakthrough occurs

The manufacturer should provide a troubleshooting guide for filtration equipment and for prefiltration equipment, if the latter was also provided. The guide should be a simple check-list of what to do for a variety of problems including:

- no raw water (feed water) flow to plant
- can't control rate of flow of water through package plant
- filter can't be backwashed or backwash rate of flow can't change
- no reading on turbidimeter
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- excessively high head loss through filter after dirty filter backwashed
- filter head loss builds up too quickly during a run
- no head loss readings
- valve stuck or won't operate
- clogged prefiltration equipment (if used)
- no electric power

The following are recommendations regarding operability aspects of backwashable depth filter package plants. These aspects of plant operation should be included if possible in reviews of historical data, and

should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program.

During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects. If prefiltration equipment is also used, operability of that equipment shall also be discussed. Among the factors that should be considered are:

- can both influent pressure and effluent pressure be measured at filter vessel?
- is rate of flow of raw (feed) water measured?
- can raw (feed) water turbidity be measured continuously?
- can filtered water turbidity be measured continuously?
- can filter bags or cartridges be replaced easily if this becomes necessary?
- does operator have a simple, reliable way of knowing the new filter bag or cartridge is installed and seated properly in the filter vessel?
- comment on operability of filtration equipment with and without use of prefiltration equipment, if filtration equipment was operated in both modes
- can operator observe backwash of granular media?
- how can operator check on condition and depth of granular media?
- susceptibility of prefiltration equipment (if provided) to clogging
- can filter cleaning be done automatically?
- if automatic cleaning or backwashing is provided, could it be initiated by:
- reaching a set value for head loss?
- reaching a set value for filtered water turbidity?
- reaching a set value for time in operation?
- does remote notification to operator occur when cleaning happens?
- does cleaning restore filter to original clean bed head loss or does higher head loss for clean filter indicate progressive clogging of filter?
- how does the operator know that the backwash cleaned the filter satisfactorily?
- can volume of water used for cleaning filter be measured?
- can the rate of flow during cleaning be controlled?
- is backwash duration (time) variable?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Operating Conditions and Treatment Equipment Performance, in the Backwashable Depth Filter Test Plan.

16.0 REFERENCES

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Table 1. Generic Schedule for Verification Testing of Backwashable Depth Filters		
Test Period	Initial Operations, Estimated Time	Verification Testing, Minimum Required Time
#1	1 - 6 weeks	30 days or more
#2 (optional)	1 - 3 weeks	30 days or more
#3 (optional)	1 - 3 weeks	30 days or more
#4 (optional)	1 - 3 weeks	30 days or more

Table 2. Water Quality Sampling and Measurement Schedule	
Sample or Measure For:	Minimum Frequency:
Temperature	Daily
pH	Weekly
Total alkalinity	Desired weekly but optional
Hardness	Desired weekly but optional
Total organic carbon	Desired weekly but optional
Turbidity	Daily at bench to check continuous turbidimeters
Continuous turbidity monitoring	Use data at 1/4, 1/2, or 1 hour for calculations of long-term performance. Also note maximum turbidity observed each day.
Iron	Once each testing period or weekly if present in concentration of 0.3 mg/L or greater
Manganese	Once each testing period or weekly if present in concentration of 0.05 mg/L or greater
Total coliform bacteria	Desired twice per week, at least 2 days apart, but optional
Algae, number and species	Weekly; 3 times per week if algae cause shorter filter runs.
UV_{254} absorbance	Desired weekly (when sample for TOC taken) but optional
For schedule for microspheres, particle counting, and *Cryptosporidium*, see Task 4. Collection of samples at times other than those specified for the minimum frequency may be appropriate to show the full range of feed water treated, if rapid and significant changes in feed water quality occur during Verification Testing.	

Table 3. Analytical Methods			
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Particle counts (electronic)	On-Site	Manufacturer	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Algae, number and species	Lab	10200 and 10900	
UV_{254} absorbance	Lab	5910 B	
Total coliform	Lab	9221 / 9222 / 9223	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	Draft EPA 1622, Korich, 1993 / see also 40 CFR 141.74 Appendix D
Microsphere counts	Lab	Li *et al.*,1997	

Notes:
1) Standard Methods Source: 18th Edition of Standard Methods for the Examination of Water and Wastewater, 1992, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 4. Backwashable Depth Filtration Equipment Description and Operating Data	
Operating Data	Action
Feedwater Flow and Filter Flow	Check and record twice per day, adjust when >10% above or below goal. Record both before and after adjustment.
Filter Head Loss (filter inlet pressure and filter outlet pressure)	Record initial clean bed total head loss at start of filter run and record total head loss two times per day.
Backwashing	Record time, date, and feed water or filtered water meter reading at time of each backwash; and calculate total water produced in the filter run. Record terminal head loss at end of run just before filter was shut off and backwashed. Note reason for backwashing, rate of flow for backwash, and volume of wash water used.
Electric Power	Record meter reading once per day.
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day. (Around-the-clock operation is recommended).
Filtered Water Production	Calculate gallons or cubic meters of water produced per filter run, and total water produced by the filtration equipment each day it is operated.
Log of events in watershed	Record occurrence of storms, construction activities, snowmelt, or other activities that could influence source water quality in log book at end of day or at beginning of shift on following work day.
Provide a complete description of the package treatment plant equipment as required in Task 3.	

Table 5. Challenge Tests and Particle Counting Schedule	
Particle Counting	
feed water	continuous or count 8 samples/day, if particle counting of feed water done on grab (batch) samples
filtered water	continuous particle counting required
Analysis of Feed Water and Filtered Water for Microspheres or Challenge Organisms (or both)	
1. start equipment after filter was backwashed	1. after equipment started up and 3 filter vessel volumes treated
2. midway in run, as indicated by filter head loss	2a. sample before stopping operation of filter
	2b. sample after filter stopped and restarted again, if filter can be restarted without backwashing
3. near end of run at 85% to 95% of total filter run head loss	3. sample before stopping operation of filter
For microsphere or challenge organism testing, must do two separate runs after the filter has been operated and backwashed.	